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GASOLINE ENGINES

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The following publication, entitled "Gasoline Engines," is published for the information and guidance of all concerned.

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GASOLINE ENGINES.

CHAPTER I.

GENERAL PRINCIPLES OF THE INTERNAL-COMBUSTION ENGINE.

INTRODUCTORY CLASSIFICATION.

Virtually all modern engines are some form of heat engines, i. e., fuel is burned to form heat from which, indirectly, is obtained mechanical motion or power. The so-called "steam" engine is a heat engine; the engine we commonly call a "gasoline" engine is a heat engine. But, the steam engine and the gasoline engine are two different forms of heat engines. In the first case the fuel is burned external to the working parts of the engine proper. Therefore, the steam engine is termed or classified as an "external-combustion engine." On the other hand the gasoline engine burns its fuel within the engine and is classified as an "internal-combustion engine," or gasoline engine. It has been called a gasoline engine because the fuel generally used is gasoline.

From the point of efficiency based upon the percentage of heat in fuel that is converted into mechanical energy, the steam engine shows an efficiency of from 5 per cent to 10 per cent, and the internal-combustion engine (gas engine) shows an efficiency of from 17 to 30 per cent.

Internal-combustion engines are best for airplanes and all types of aircraft, as they are the lightest and most efficient of prime movers. The fuel consumption is twice as great in a steam-power plant (owing to heat losses) as would be the case in a gasoline engine of equal power and much less weight.

FUEL.

Illuminating gas, kerosene, crude oil, alcohol, gasoline, and many other combustible materials have been used for operating internal-combustion engines. Oxygen, which is contained in the air, has in all cases been used as the supporter of combustion.

Gasoline is the fuel used in all airplane internal-combustion engines. It is most desirable for the following reasons:

(*a*) Can be obtained in large quantities.

(*b*) Cost is comparatively low.

(*c*) Can be easily vaporized at atmospheric temperature.

(*d*) Explodes rapidly, allowing the engine to run at high speed, thus permitting the use of a small, light engine of ample power.

(*e*) Is in a form which is easily handled, and for a given volume and weight will furnish sufficient heat units to run a powerful motor for a considerable period.

COMBUSTION.

When two materials, one a combustible material and the other a supporter of combustion, are mixed together and then raised to the temperature at which they were combined a chemical change takes place and heat is liberated. A certain amount of heat is necessary to start the chemical action, but once started the heat liberated will be sufficient to continue the action until one or both of the materials have been exhausted. Such a chemical change is called combustion. Combustion is very common in nature. A stick of wood when once lighted will liberate heat. A piece of iron when exposed to the air will combine with oxygen in the air and form rust or iron oxide. Vegetable matter combines with oxygen and decays. These are all forms of combustion, but many of them occur so slowly that we do not think of them as such. When combustion occurs very rapidly we call the action which takes place "explosion," and it is this form of combustion with which we are chiefly concerned in our study of gasoline engines. Heat which is liberated during explosion may do two things: First, the chemical change may be such that a dense substance is changed to a light substance, which, under the same pressure, will occupy a greater volume (for example, gunpowder changes to a gas which is chiefly dioxygen; gasoline changes to carbon dioxide gas). Second, the heat of the explosion will cause the gas to expand if under a given pressure or if confined the pressure will rise. When properly confined a compressed gas can be made to perform useful work.

When a fuel such as gas is admitted to the cylinder of an engine a certain quantity of air is admitted at the same time to furnish the necessary oxygen for combustion. Before ignition this mixture is compressed into a small space. This compression serves to mix the particles of air and fuel more intimately and to raise the temperature of the mixture. This compressed mixture will ignite with more certainty and will burn more evenly than a rarer and colder mixture.

The heat energy thus liberated does mechanical work in the following way: Combustion causes the temperature of a certain quan-

tity of gas trapped in the cylinder of the engine to rise. This rise in temperature is accompanied by a rise in pressure of the gas. The action which takes place and which appears to be an explosion is in reality a progressive combustion and subsequent expansion of the products of combustion. The pressure thus created forces the piston toward the crank end of the cylinder, thus performing work. Motion of the piston by means of the connecting rod is caused to turn the crank. Forceful rotation of the crank performs work which is the function of a gasoline engine.

THE RELATION OF PRESSURE, VOLUME, AND TEMPERATURE INSIDE THE CYLINDER.

The actual laws by which the pressure, volume, and temperature of gas vary and the relation between them is a rather difficult study for the average mechanic. Without giving mathematical relations the following general principles should be thoroughly understood by the student:

The charge taken into the combustion chamber of an internal-combustion engine is not a perfect gas, but for our present purpose we may think of it as such. A body of gas possesses weight, which, for a given amount of gas, remains always the same. However, the gas may occupy a large or small space and may be at high or low temperature. If contained in an inclosed space, a pressure will be exerted by the gas on the walls of the container, which is equal in all directions.

MEAN EFFECTIVE PRESSURE.

In many instances the "brake mean effective pressure" of an engine is spoken of. By this is meant the mean effective pressure which, if exerted on each piston during its power stroke for the entire length of the stroke, would develop the brake horsepower of the engine. Thus, with a constant pressure, there is a certain force acting through a certain distance a certain number of times every minute, and the horsepower developed can be determined by dividing the foot-pounds of work done per minute by 33,000.

"p" equals the brake mean effective pressure in pounds per square inch.

"l" equals the length of stroke in feet.

"a" equals the area of the piston in square inches.

"n" equals the number of explosions per minute, which is equal to the number of cylinders divided by 2 and multiplied by the revolutions per minute.

Then brake horsepower equals "plan" divided by 33,000. Knowing the brake horsepower, bore and stroke, and the revolutions per minute, the brake mean effective pressure can readily be determined.

The fuel consumption of an engine is usually stated in pounds of fuel per brake horsepower hour, meaning that a certain amount of fuel is used when the engine develops the brake horsepower for the period of an hour. This value is obtained by running fuel consumption tests and dividing the fuel consumed per hour by the brake horsepower developed.

ATMOSPHERIC PRESSURE.

The atmosphere exerts a pressure on objects due to the weight of the air above us. At sea level the weight of the air is equal to 14.7 pounds for each square inch of the earth's surface. Consequently when we speak of a vacuum or suction, we simply mean that the pressure which the gas exerts on the wall of the container is less than atmospheric pressure.

TEMPERATURE.

When heat is applied to a mass its temperature rises, and when heat is taken away the temperature of the mass goes down. Heat always travels from points of high temperature to points of low temperature when allowed to take its own course. In measuring temperature we use the term "degree," which is simply an arbitrary unit. There are two scales for measuring temperature—the Centigrade and the Fahrenheit scale. Zero degrees on the Centigrade scale corresponds to 32 degrees on the Fahrenheit scale, which is the temperature at which water freezes at sea level. It must not be assumed, however, that these points represent the temperature at which all heat is absent, for such a point is far below zero on either the Centigrade or the Fahrenheit scales and is known as the "absolute zero." One degree Centigrade is equivalent to 1.8 Fahrenheit. As the Fahrenheit scale is the one with which we are all familiar, it will be used in this text. Absolute zero, or the point at which there is no heat, is 460 degrees below zero on the Fahrenheit scale, so that 32 degrees Fahrenheit is equal to 460 degrees plus 32 degrees, or 492 degrees absolute.

VOLUME.

Volume is the space occupied by a mass and is measured in cubic inches, cubic feet, etc.

RELATION OF VOLUME TO PRESSURE AT CONSTANT TEMPERATURE.

In thinking of the changes in pressure and temperature we must think of the change in relation to absolute zero, pressure, and temperature. When the volume, pressure, or temperature of a given weight of gas is changed one or both of the other two must also be

changed. If pressure changes and temperature remains constant, then with increased pressure volume must decrease and with decreased pressure volume must increase.

RELATIONS BETWEEN PRESSURE, VOLUME, AND TEMPERATURE.

If volume is held constant and temperature increased, the pressure will rise, but if temperature is lowered the pressure will fall. If pressure is held constant and volume increased, the temperature will fall, but if volume is decreased the temperature will increase. The above may be expressed as follows: For a given weight of gas, the pressure multiplied by the volume and divided by temperature remains always the same, no matter what changes take place in the gas, providing that pressure and temperature refer to absolute values and not values measured from atmospheric pressure and zero Fahrenheit. The application of the above principles is presented in the paragraph on the four strokes of the cycle.

HEAT.

Because heat controls the basic principle of the gasoline engine, it is best in a brief way to consider its application. Whenever a solid substance is heated, considering everyday substances, a cubical expansion takes place. The substance will grow longer, wider, and thicker with each degree of heat added, so that in some cases the expansion is very noticeable. Of course, if heat is continually added the substance will in time fuse and lose one of its physical characteristics, commonly called "shape." Air, which is a gaseous substance, when heated expands on the same general principle as a solid substance. Each degree of heat added to a volume of air or similar gas expands it, the volume becoming greater if the pressure is kept uniform.

Most gases expand very rapidly when heated, so much so that if a material change of temperature takes place a considerable expansion would be noted. Nearly everyone has witnessed the rising of a hot-air balloon. Such a balloon is generally inflated by supporting its envelope over a bonfire. The air in the balloon is hot air or expanded air and occupies more space than cold air would, and is therefore lighter than cold air. As a result the balloon will float upward in the atmosphere, and if well inflated with hot air will very naturally support some weight.

If a volume of gaslike air be heated within an inclosed vessel so arranged that the gas is not free to expand, then the pressure within the vessel will be increased. If the heat is continued to any high temperature and the vessel be not very strong it will burst by reason of the pressure generated. Suppose we have a cylinder and piston

arrangement so that it can not be moved; imagine there is absolutely no leakage. Now, if this charge is ignited the temperature and pressure will run up very high. After five minutes we would find very probably only a few ounces of pressure remaining. The reason for this is that the cool cylinder and piston have absorbed the heat of the explosion, and as the heat subsides the pressure subsides. In other words, the hot gases have contracted in cooling. Heat and pressure can be considered practically the same thing in studying the gasoline engine.

The two features which stand prominently in the adaptability of an engine for airplane use are the weight per horsepower and the weight of fuel per horsepower developed.

All the heat which shows up in the engine in one form or another comes from the fuel used. Part of the heat of the fuel is transformed to work at the engine shaft, and the ratio between this heat and the heat in the fuel is called the "thermal efficiency." During the exhaust stroke the gases are rejected at a high temperature and the heat in these gases is wasted or lost. Some heat is also dissipated by radiation, since the temperature of the engine is higher than the surrounding medium. During combustion, high temperatures are reached and certain parts of an engine require cooling, or hot points would develop and cause preignition, or perhaps the destruction of the oil filament. The internal-combustion engine being a mechanical device, loses a certain amount of heat or work through friction. The ratio between the work done at the shaft to that on the piston is called "mechanical efficiency." Summing up the various heat losses is usually referred to as a "heat balance." The following is a typical heat balance:

	Per cent.
Heat transformed to work	21
Heat lost to exhaust and radiation	37
Heat lost to cooling system	36
Heat lost to friction	6
Heat in the fuel	100

The thermal efficiency is twenty-one one-hundredths, or 21 per cent. Therefore, with the best gasoline motors we make we use only about 21 per cent of the heat value of the fuel, or, in other words, we lose four-fifths of the heat or power that is in the fuel. These figures are only approximate, but should serve to give an idea of where all the power of heat goes.

Work is done whenever a force moves through a distance.

Power is the rate of doing work.

Energy is the capacity to work.

Efficiency is the ratio of useful work to input.

In the first gas engines made, gas was drawn into the cylinder and burned without being compressed. The result was that it required a great deal of gas to develop a given amount of horsepower. In other words, the engines were not economical. It was found that by compressing the gas before the charge was fired it was possible to obtain a great deal more power with the same amount of fuel. When gas is compressed it will burn much more rapidly. Naturally, in a motor running at the high speed that our airplane motors do, the gas must be burned completely in a very short space of time in order to do any work. Therefore, it is made plain that if a motor is to run it will be necessary first to draw gas into the cylinder, then compress it, then it must be burned and expanded and the burned gas cleared out of the cylinder. These four things must be done in any gasoline motor. After the gas is compressed in the cylinder its temperature rises to a certain extent. Then the heat of the electric spark which is used for ignition causes a further rise. The heat of the spark, together with the heat of the compression, is sufficient to ignite the gas or start its burning. Then, as the gas burns its temperature and pressure will rise very rapidly. If the gas were not confined, the temperature would go quite high, but when burned in a confined space pressures are increased as the gas burns. This increase in pressure adds to the head, as also does the burning of the fuel. Therefore we obtain a temperature in a gas-engine cylinder of between 2,600° and 3,000° F. You can think of this as a white-hot flame.

CHAPTER II.

THE CYCLE OF OPERATIONS.

A cycle is a series of events which upon completion are repeated in the same order.

An internal-combustion engine cycle consists of (1) intake, suction, or admission of the charge; (2) compression; (3) ignition, combustion, and expansion; (4) exhaust.

The number of strokes necessary to complete this cycle gives a means of cyclic classification, as follows: (1) Two-stroke cycle; (2) four-stroke cycle. The latter is sometimes called the "Otto cycle." The two-cycle is sometimes called the "Clark cycle."

THE LENGTH OF AN ENGINE CYCLE.

The observed performance of an engine is always based upon the action of its piston. When a piston moves from one extreme end of its travel to the other, as from the highest point to the lowest point, the movement is termed a "piston stroke." One complete revolution of the crank shaft would carry the piston through two piston strokes, one "down stroke" and one "up stroke." The two-cycle engine completes its program of events in two strokes of the piston and one revolution of the crank shaft. The four-cycle engine completes its program in four piston strokes or two complete revolutions of the crank shaft.

THE TWO-STROKE CYCLE ENGINE.

The two-cycle engine is the simplest, because there are no valves in connection with the cylinder, as the gas is introduced into that member and expelled from it through parts cored into the cylinder walls. These are covered by the piston at a certain portion of its travel and uncovered at other parts of its stroke. In the four-cycle engine the gas is admitted through a port at the head and closed by a valve, while the exhaust gas is expelled through another port controlled in a similar manner. These valves are operated by mechanism distinct from the piston.

OPERATION OF THE TWO-STROKE CYCLE TYPE ENGINE.

(*a*) During the upward motion of the piston a fresh charge has been compressed. Just before head dead center is reached, ignition takes place.

(*b*) Inertia carries the piston over head dead center and the expanding gas drives the piston downward on its power stroke. Some time before crank dead center is reached the piston uncovers the end of the transfer passage. Now, during its downward motion the piston has compressed to a pressure of about 7 or 8 pounds a mixture of line vapor and air in the crank case. When the transfer passage is opened this pressure causes a new charge to rush into the cylinder. Arriving there it expands, strikes the deflector, is deflected upward, thus aiding in exhausting the burnt gas from the cylinder.

(*c*) Soon after the piston has passed crank dead center, its upward motion covers the transfer passage, and not long after that covers the exhaust port, thus trapping in the cylinder a quantity of explosive mixture. The continued motion of the piston compresses this charge at the same time, creating a suction in the crank case which draws into the crank case the next fresh charge. At the proper time ignition takes place as above described, and the cycle is repeated. All these things have been accomplished in two strokes of the piston or one revolution of the crank shaft.

FOUR-STROKE CYCLE TYPE.

Practically all engines now in use in airplanes are of four-cycle or, more correctly speaking, four-stroke cycle type.

On the first down stroke of the piston, called the "intake stroke," the inlet valve opens and a charge of fuel and air is sucked into the cylinder. The inlet valve is then closed, and the piston moves up on the second stroke, compressing the gas. Next the spark occurs, igniting the charge, causing the pressure to raise, which forces the piston out on its third stroke, which is called the "expansion" or "power stroke," pushing the burnt gas out of the cylinder through the exhaust valve. The exhaust valve then closes, completing the cycle of four strokes.

To sum up: The four-cycle motor requires four strokes to complete its program or cycle. These strokes are (1) intake or suction, (2) compression, (3) expansion or working stroke, (4) scavenging or exhaust stroke.

THE FOUR STROKES AND THE DUTIES OF EACH.

As explained before, in each cylinder four strokes of the piston are required to complete the cycle of operation.

INTAKE STROKE.

We will start with the piston on top dead center at the beginning of the first down stroke of the cycle. After moving down a very short distance the exhaust valve closes and the intake valve opens, connecting the cylinder to the intake manifold, which is in turn connected to the carburetor. As the piston continues downward, the volume of the cylinder is increased, causing the pressure to fall below that of the atmosphere. This causes a flow of gasoline and air into the mixing chamber of the carburetor where they are mixed, forming a vapor which flows through the intake manifold and intake valve port to the cylinder. The pressure in the cylinder remains below atmospheric pressure to the end of the stroke and for a short time after the piston has started up on the following stroke. The inertia of the incoming gas mixture also tends to keep it flowing into the cylinder, even though the mixture has reached a pressure equal to that of the atmosphere.

CLOSING OF INTAKE VALVE.

For the above reason, the intake valve is not closed until the piston has traveled upward a short distance on the second stroke, allowing the maximum charge to enter the cylinder.

COMPRESSION STROKE.

As the piston moves upward on the second stroke, the intake valve closes. Then, due to the decrease in volume as the piston continues upward, and the increase in temperature, due to compression, and absorption of heat from the cylinder walls, the pressure of the gas is increased. The pressure at the end of the compression stroke in an engine with five to one compression ratio will be about 70 pounds per square inch, gauge pressure of about 85 pounds per square inch absolute when the engine is developng its maximum power.

WHY THE CHARGE IS COMPRESSED BEFORE IGNITION.

By compressing the gas before ignition, the pressure after ignition is greater in proportion to the compression ratio, so that a motor developing a given power may be made very small as compared to one which does not compress the gas before ignition. The temperature of the gas when ignited rises to about 2,700° F., and if the cylinders were not artificially cooled they would melt after a few explosions. In cooling the cylinders, heat is taken from the exploded gas, causing loss of power. The greater the surface of cylinder wall exposed to the cooling water, the greater

will be the loss of power. By compressing the gas before ignition, the area of the cylinder walls is greatly reduced, consequently the engine will be much more efficient. The object, then, in compressing the gas before ignition is to reduce the size of the engine and increase the efficiency. When gas is compressed above a certain limit, the temperature of compression becomes so great as to cause preignition.

The average practice of the compression in any automobile motor cylinder is 65 pounds to the square inch. The aviation motor operates with much higher compression, for the reason that they ascend to high altitudes. The effect of ascending to an altitude of less dense air is to lessen the compression within the cylinder. An airplane motor, built for an ascent of 20,000 feet, must have a much higher compression than one only intended for an ascent of 5,000 feet. Motors intended for high altitude flights are labeled "high compression." This compression may reach 135 pounds to the square inch. Those intended for low altitude flights, such as Navy observation work, are marked "low compression." This compression will range from 85 to 105 pounds to the square inch.

IGNITING THE CHARGE.

Approximately, at the end of the compression stroke, the charge is ignited by means of an electric spark. A short time is required after the spark occurs for the flame to be propagated throughout the charge, and for this reason, except for starting, the spark occurs a little before dead center, the amount of advance depending upon the engine speed. When the charge is fired, the temperature suddenly increases to about 2,600° to 2,800° F.. causing a great increase in pressure. Thus the chemical energy contained in the charge is converted to heat energy. An engine with five to one compression ratio develops a maximum pressure of about 250 to 300 pounds per square inch.

POWER STROKE.

After firing the charge, the high pressure developed forces the piston down, thus converting heat energy into mechanical energy. As the piston travels downward, the volume of the cylinder increases, causing a drop in pressure. The temperature also drops, due to the expansion and to loss of heat through the cylinder walls. If the exhaust valve were not opened until the end of the stroke a greater average force would be exerted by the gas on the piston during the power stroke, but the pressure in the cylinder at the beginning of the following upward stroke would act against the piston, resulting in

negative work. It has been found by experiment that the engine will deliver maximum power if the exhaust valve be opened from about 40 to 60 degrees before bottom dead center, at which point the pressure in the cylinder will equal about 40 to 50 pounds per square inch (5 to 1 compression ratio).

EXHAUST STROKE.

As the piston starts up on the fourth stroke, the exhaust valve is opened and the burnt gases are forced out through the exhaust port, exhaust manifold and muffler. A great amount of heat energy is contained in the exhaust gas, which, however, can not be converted in the engine. In order that the fresh charge taken in on the following intake stroke may be of maximum value, it is desirable to exhaust as much of the burnt gas as possible. At the end of the stroke, the burnt gas in the combustion chamber is still under pressure greater than the atmosphere. For this reason and because of the inertia of the outgoing gas, the exhaust valve is not closed until a few degrees after the piston has passed top center. The above events are then repeated over and over again, each repetition being one cycle.

TWO-CYCLE ADVANTAGES.

No valves, valve gear, cams and cam shaft, more uniform turning movement, smaller cylinder volume per unit of power. Closing of valves is not dependent on springs; therefore, engine may be made to run at higher speeds (5,500 revolutions per minute).

TWO-CYCLE DISADVANTAGES.

Loss of fresh fuel with exhaust reduces the economy; crank case must be kept gas tight to prevent loss of fuel and compression; fresh fuel entering the cylinder full of hot exhaust gases may cause premature explosion, and if this occurs before the admission port is closed, the crank case charge may explode, causing considerable damage to engine. For large engines an auxiliary pump is employed to replace crank case compression.

FOUR-CYCLE ADVANTAGES.

Better explosion control; more economical; compression not dependent upon tightness of any part except valves and piston rings.

FOUR-CYCLE DISADVANTAGES.

Cylinder volume and weight per unit of power greater; multiplication of parts, especially valves, valve gear, cams, countershaft, etc., with loss of power if any valves are not gas tight.

The four-cycle engine seems to lose in simplicity by comparison with the two cycle, but it is in far more common use. The two-cycle engine has given way to the four-cycle type for airplane use.

Although the two-cycle engine receives twice as many impulses per revolution as the four cycle, it must not be concluded from this that, for the same cylinder dimensions, the two cycle has twice the power. In the four-cycle type the impulse, due to expansion, is carried throughout nearly the entire stroke, whereas in the two-cycle type the exhaust valve opens much earlier and the impulse only lasts about five-eighths of the stroke.

MEASURING PARTS OF REVOLUTIONS—DEGREE MEASURE.

In order to a little more fully explain the principles involved in the gasoline engine it will be necessary to refer to a partial revolution of the crank shaft, such as a half revolution, a quarter revolution, or some smaller fractional turn. To state definitely what part of a turn it is desired to express recourse is made to what is called "sexagesimal" or "degree measure."

The degree is the one-three hundred and sixtieth part of the circumference of a circle. If a circle had a circumference of 360 inches in length then each inch would represent a degree. A quarter of a circle would be 90°; a half circle 180°, etc. The word "degree" originates with the ancients of early Babylon; these ancients indicating that the earth required 360 days to pass its circular orbit around the sun; hence the division of a circle into 360 parts. If a crank shaft is given one quarter turn it is said to have turned "through an effort of 90°." A turning effort of the crank shaft of 360° would represent one revolution; two revolutions measured in succession would be 720°. The gasoline engine cycle is, therefore, 720° of crank-turning effort in length.

MORE EXACT INFORMATION ON THE STROKES OF A CYCLE.

Thus far it has been indicated that the power stroke, exhaust stroke, etc., of the gasoline-engine cycle are each approximately one-half revolution in length. In actual practice on the motor this is not true; the strokes vary more or less from 180°, according to the design ideas expressed in the construction of the motor. For example, one well-known motor has a cycle whose strokes are as follows:

	Crank-turning effort.
Intake stroke	215°
Compression stroke	135°
Power stroke	130°
Exhaust stroke	240°
The complete cycle	720°

It will be noticed that the power stroke is less than one piston stroke of 180°. The exhaust stroke, on the other hand, is much longer than a piston stroke (it being understood that a piston stroke has the definite length of 180°). These events of varying length are called "cycle strokes" in order to distinguish them from the so-called "piston strokes" of the motor. Motors will differ in their design, depending upon many little details of construction, and will differ as to the exact lengths of the cycle strokes. For example, another well-known motor, instead of having a power stroke of 130°, has a power stroke of 135°; while still another has a power stroke of 128°. In fact, each designer in planning out the details of a motor is very likely to express a difference in cycle-stroke lengths from that of any other motor. The reason for these varying lengths will be fully explained in the subsequent chapter.

COMPARISON OF AIR AND WATER COOLED TYPES.

The metal weight of the water-cooled motor is about one and one-half times that of the air-cooled motor. The consumption of the air-cooled motor is approximately twice that of the water-cooled motor.

The air-cooled motor can run at higher temperatures than the water-cooled motor; and as there is less difference in temperatures between the cylinder walls and the heat of explosion, there is less loss of heat by radiation, or less "heat loss." The air-cooled system is simpler and lighter than the water cooled. It has no freezing troubles in winter, but as it runs hotter, this means lower compression must be used, because on hot days, with the atmospheric temperature higher, the cylinder temperature will run higher, and the cylinder temperature may be several degrees hotter. This means the designer has no upper limit on his temperature and must make the combustion chamber of a size which will give a compression suited to the highest likely temperature. This means comparatively low compression. With water-cooled motors, as the water temperature reaches 212 degrees (boiling point of water), the water is rapidly lost. Therefore there is quite a definite upper limit to the temperature at which this type of motor can be run, and this means that a comparatively high compression can be used and better fuel economy obtained.

A motor which has excessive compression will run well for a short time, then will lose power from preignition. Airplane motors are particularly likely to be troubled this way, as they are run continuously on full throttle, which also means full compression.

A disadvantage in connection with the cooling of a rotary engine is that the leading edge of the cylinder is much cooler than the

trailing edge; this gives a difference of temperature around the cylinder walls, producing a distorted cylinder, and so necessitating the use of a special type of piston ring which is known as "obdurator ring." This type of ring is fitted because it will easily follow the distortion of the cylinder, thus keeping the piston compression tight in the cylinder. This ring is a constant source of trouble.

Summing up: The advantage of the water-cooled engine is longer life and a higher thermal efficiency, due to a smaller loss of work from overheating. The disadvantages attached to a water-cooled engine from an aeronautical point of view are that it is much heavier and the possibility of trouble due to freezing of water.

CHAPTER III.

THE VARYING LENGTHS OF CYCLE STROKES.

PECULIAR RELATION BETWEEN PISTON AND CRANK-PIN TRAVEL.

The definition of a piston stroke has already been given. Its proportionate travel, however, in connection with equal movements of the crank pin upon the crank path circle has not been explained, yet this explanation is necessary to fully understand the "why" of the cycle stroke lengths. Note the diagram below: *D* is a crank path circle with a cylinder center line drawn through it. Naturally, as the crank pin travels over the crank path circle *D*, the piston will move to and fro along the cylinder center line, as indicated by the bracket labeled "piston stroke." Between top center "0" and bottom

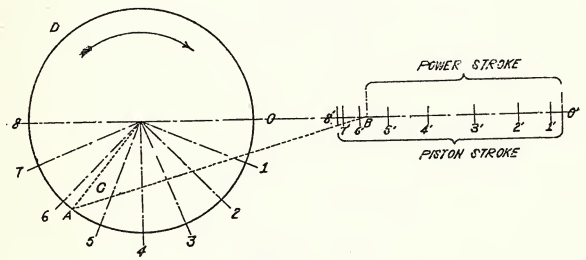

FIG. 1.

NOTE.—"A" for crank pin position and "B" for piston position in the figure, the exact setting at 130°. A comparison of the power stroke to a full piston stroke is thus easily made. The length of the power stroke is so much greater than would be imagined that it hardly seems credible.

center "8" a number of equal distances upon the crank path circle have been stepped off. There are eight of these distances between the centers, each being equal to $22\frac{1}{2}°$. Now, when the crank pin is at point 1, the piston will occupy a relative position as point 1′ in the piston stroke, and so on, for the following points, 2, 3, 4, etc., to bottom center. It becomes apparent in observing the movement of the piston, as compared with the equal crank pin movement, that the piston moves large distances between points 2′ and 5′, and small distances between 0′ and 2′, as well as between 5′ and 8′. As a result, when the crank pin is at 90°, point 4, the piston is more than

half way down in its stroke. If the average crank pin travel of a power stroke is 130° less than three-quarters the distance from top to bottom center, then the corresponding travel of the piston will be approximately nine-tenths a full piston stroke.

EARLY AND LATE VALVE OPENINGS.

The two main observation points on the crank path circle are the two centers, top center and bottom center. If any mechanical event occurs when the crank pin is in the neighborhood of one of these centers, it is said to occur "early" or "late," according to whether it happens before the crank pin reaches the center, or after. For example, suppose the power stroke to be approximately 130° long and to start at top center. The exhaust valve would then open 130° after top center, or, in the usual shop language, "50° early," meaning 50° before reaching bottom center. Now, again, if the exhaust stroke was 240° long, the exhaust valve would close "10° late," or 10° past top center. Thus, one mechanic may say to another, "How late is the exhaust closing on this motor?" The reply would give him the exact timing he sought, as it would be expected of him to know which of the two common centers were referred to.

WHY THE EXHAUST VALVE OPENS EARLY (BEFORE BOTTOM CENTER).

As we enter into a simple discussion of the exhaust valve timing, it is best that first a conception of motor speed be obtained. A little thought applied to the subject will recall that the slowest propeller speeds are in the neighborhood of 1,200 revolutions per minute. The fastest speeds are around 1,700 revolutions per minute. These speeds, of course, are those attendant upon maximum motor effort. It is customary, in the cases of all motor speeds less than 1,700 revolutions per minute, to "direct connect" the propeller to the crank shaft of the motor. So, if the average propeller speeds lie between 1,200 and 1,700 revolutions per minute, then, so do the average motor speeds. Let us select for illustration a motor speed of 1,400 revolutions per minute. Then, since there are 60 seconds to one minute—

1,400 divided by 60 gives 23.333 or 23.333 turns a second.

1 piston stroke equals one-half revolution. 23.333 revolutions per second means one revolution is made in $\frac{1}{23.333}$ part of a second.

One-half of $\frac{1}{23.333}$ is $\frac{1}{46.666}$ or $\frac{1}{46.666}$ part of a second.

Thus we find that a piston stroke is completed in one forty-sixth to one forty-seventh of a second, a very short period of time.

In dealing with the gasoline engine it is a good plan to bear in mind that nothing can happen "instantaneously," though certain happenings may occur with startling rapidity; a time interval must always be allowed to "cover" the performance. A good illustration of this is the duck hunter. When a hunter fires at a duck on the wing, passing by him, he must aim a certain distance ahead of the duck. If he aims at the duck, and the gun shoots true, he will miss it to a certainty, unless the duck is very close to the gun. The reason for this is that a time element is required for the trigger hammer to fall on the cap, the powder to burn, and the shot to travel the distance from the gun to the position of the duck. During these happenings the duck is moving. This is also true of many instances of the gasoline engine; an "advanced timing" is required, that the happenings may be in keeping with the great piston speeds.

If all downward strokes of the piston were accompanied by a positive pressure upon the piston head, and all upward strokes by a negative pressure, the engine conditions would be ideal. Such conditions are impossible; the best that can be hoped for, especially in considering the power and exhaust strokes, is that the pressure during the power stroke be as great a positive pressure possible to be obtained from the fuel, and that the exhaust stroke be as mild as a positive pressure consistent with the ejection of the burnt gases. The exhaust stroke, then, at the best will have a retardant effect upon the piston. It will further follow, that whenever the pressure is positive within the combustion chamber of the cylinder, it will voluntarily move out to the atmosphere if an escape passage is provided. The outrush will depend on how positive the pressure is.

In referring to the travel of the piston downward during the power stroke (see Fig. 1), the major movement has occurred prior to point 6, approximately 135°. The final 45° to bottom center results in but slight piston movement. The operative pressure of the gases forcing down the piston has been greatly reduced by the time point 6 is reached. The piston has already permitted an extensive enlargement of the combustion chamber. Why, then, not utilize the opportunity afforded by the final 45° or so to effect a voluntary unloading of any positive pressure within the combustion chamber? This would bring the pressure more nearly normal at bottom center, and the piston could then start its next upward stroke with less retardation.

Summing up the above, the following defined reasons can be assigned to an early opening of the exhaust:

(*a*) When the crank pin reaches the neighborhood of 45–50° before bottom center, the piston has performed the major part of the first piston stroke and has allowed for all reasonable expansion of the power gases.

(*b*) The great rapidity of piston movement is such that unless an "early exhaust" is started, bottom center will be passed with an undesirable pressure still reposing in the combustion chamber space.

(*c*) After passing the neighborhood of 45–50° before bottom center, "the cranking angle" is such that the connecting rod can no longer impart rotary motion to the cranks to advantage. (See angle C, Fig. 1.)

(*d*) The terminal pressure of the power stroke, though only a fraction of the beginning pressure, is still highly positive (about 40 pounds to the square inch) at 45–50° before bottom center and will voluntarily rush out if the exhaust valve is opened, thus effecting a large volume of the exhaust without piston retardation.

(*e*) The power gases and exhaust gases are extremely hot, and the longer they repose in the combustion chamber space the more heat they radiate to exposed surfaces, thus breaking down lubricants and interfering with proper cooling. The earlier the exhaust is started the less this trouble.

THE EXHAUST STROKE.

The exhaust stroke is the longest cycle stroke of the four. It is much over the length of the complete piston stroke, and therefore must not at any time be imagined as an upsweep of the piston merely. Naturally, the air-cooled motors have longer exhaust strokes than the water cooled, as the average air-cooled motor opens its exhaust valves earlier. In fact, some air-cooled motors start their exhausts as early as 85° before bottom center.

It might be said here, just to convey a comparative idea, that the average water-cooled motor starts the exhaust 50° before bottom center, while the average air-cooled 70° before bottom center.

That part of the exhaust stroke occurring prior to the passing of bottom center by the crank pin is usually termed the "voluntary portion," while that part existing between bottom center and top center is usually termed the "forced portion." And, as will soon be seen, the exhaust continues past top center some 10° on the average, forming a portion usually termed the "second voluntary portion."

WHY THE EXHAUST VALVE CLOSES AFTER TOP CENTER.

If the student will pick up a detached cylinder, turn the open bore toward him, and glance down the bore, he will observe that the valve heads are comparatively small. Yet it is through these valve ports that all gases must find ingress and egress to the cylinder. The engine designer is always studying methods of making the valve ports as large as the practicalities in construction will permit him.

It is observed, however, that during the upward movement of the piston through the exhaust stroke its velocity becomes so great that the stale gases can not hope to escape in the proper proportion. Thus, the piston reaches the top of its travel with a slight congestion of the exhaust gas ahead of it confined in the combustion chamber. The pressure is, therefore, slightly positive at top center. To close the exhaust valve now would be confining burnt gases capable of voluntary ejectment. The natural place for the exhaust valve to close would be upon a normal pressure, which is likely to be reached in the neighborhood of 10° past top center.

In the block testing of motors it has been determined that the exact timing of the exhaust closing is a very critical setting, a variation of 5° too early or 5° too late, greatly affecting the horsepower delivered by the motor at full-load high speeds.

If irregularities are experienced in the valve-operating mechanism of a motor, and these irregularities affect the valve timing, it is much better to introduce them, if possible, upon the opening rather than the closing. For example, suppose the exhaust on a given motor should open 50° early, bottom center, and close 10° late, top center, a total exhaust-opening dwell of 240°. Instead, it is found that the best possible opening dwell to be had is only 235°. Question: Shall we let the valve open on time or close on time? Answer: It should open 5° late and close on time.

THE OPENING OF THE INLET VALVE.

Up to a very recent date aviation motors differed widely in respect to the opening of the inlet valve upon comparison of their cycles. Of course, the different speeds and different valve sizes and designs had a great deal to do with the variation. Recent American practice places the inlet opening within a 5° range of the exhaust closing, while generally speaking the inlet opens as the exhaust closes.

When the inlet valve opens before the exhaust valve has fully closed, the valves are said to have a "positive overlap" in their timing. Also when the inlet valve opens before top center this term is frequently applied, as, so one would suppose, any period prior to top center rightfully belongs to the exhaust stroke.

When the inlet valve opens exactly as the exhaust closes the valves are said to be "simultaneously timed."

When, as in many cases, the inlet valve opens a few degrees after the exhaust has closed, a "valve timing interval" is said to exist.

THE PRINCIPLE ATTRIBUTED TO THE VALVE TIMING OVERLAP.

The opening of the inlet valve a noticeable time prior to the exhaust closing is only done upon very high-speed motors; motors turn-

ing over faster than 1,800 revolutions per minute as a rule. This principle of valve timing is based upon the fact that a volume of gas inclosed within a pipe has weight and therefore inertia.

Each unit volume of gas or air has weight, just as any other substances, whether fluid or solid, would be expected to have weight. If, then, a volume of gas is started down a tube or pipe, the moving mass, due to its weight, will require a force to stop it. Due to the extreme lightness of most gases, they must gain considerable velocity before their momentum represents any appreciable inertia; that is, requires any appreciable force to bring them to an abrupt full stop. With the same idea in mind, a given volume of gas at rest in a pipe will resist a sudden start, all due to its weight, or, properly speaking, its inertia.

Now, if the high-speed motor has a well-developed exhaust pipe or manifold, the exhaust gases may attain an enormous velocity through it, thus possessing considerable inertia. This will frequently happen when the exhaust pipe is only 4 to 8 inches long. It then follows that the piston reaches top center during the exhaust stroke; the escaping exhaust gases, due to their inertia, will exert a "drag" or suction action on the contents of the combustion chamber, resulting in the rapid lowering of combustion-chamber pressures. Provided the exhaust valve opens early enough, giving the exhaust a good voluntary start, the action described above will bring the pressure within the combustion chamber slightly below normal at top center. If then the inlet valve be opened, this slight negative pressure will help overcome the inertia of the stationary intake gas.

The plan of the positive valve overlap is considered by many a dangerous backfire hazard. For if the motor be not fully up to speed and quick operation be given the throttle, it is almost certain to backfire, with the usual danger of setting fire to the carburetor. Also in the event of failures of the ignition apparatus or other motor assemblies the backfire seems more likely to occur.

The simultaneous valve timing or an interval of 3 to 5 degrees seems to be best thought of by the average motor operators, and most of our American training planes have been characterized by this type of motor. The new Liberty expresses this characteristic of valve timing.

WHY THE INLET VALVE CLOSES.

It is well to remark here that the intake air passes a rather tortuous passage in reaching the inlet valve port. Every turn the column of air makes means added resistance. First, are a number of turns through the preheater stove; second, down the supply pipe to the carburetor scoop; third, through the carburetor with its Venturi

choke; fourth, up a bending manifold; and, lastly, through the twists and turns of passing the inlet valve. All of this is resistance. Now, keeping in mind the above resistance, remember the rapid down movement of the piston and it should not be hard to conceive that bottom center is reached with the pressure within the combustion chamber still negative. As long as this pressure remains below the normal the new charge will continue to flow in. During the next 30° the piston will move up but little. The inlet valve is therefore allowed to remain open until by reason of the combined results of the continued inflow of the new gas and a slight uptravel of the piston the internal pressure is approximately equal to the atmosphere. This will be some 35° or 40° past bottom center on the average motor.

CHAPTER IV.

TYPES OF MOTORS.

CLASSIFICATION.

Aero engines may be divided into two main classes, rotary and stationary. Engines of the stationary class may be further divided into the radial, vertical, and vee types, all of which may be air or water cooled.

RADIAL ENGINES.

In this type of engine the cylinders are placed around a single crank pin in the same manner as the spokes of a wheel are placed around a hub. This type gives a very short and rigid shaft. The crank case also is a strong barrel type of case not divided in the center. Collection of oil is kept out of the lower cylinders by keeping the crank case pumped out. This type of motor is hard to inclose in a stream-line hood.

In comparison with other stationary engines, the radial engine has the advantage of very low overall length. Engines of this type are not at present as popular as they were formerly.

ROTARY ENGINES.

Cylinders in this type of engine are arranged the same as the radial but operate differently. In this case the cylinders revolve and the crank shaft remains stationary. The crank shaft is bolted to the airplane and the propeller is attached to the crank case, just the reverse of the practice with stationary cylinder motors.

The rotary engines combining the principles which tend to lighten the weight, as in radial motors, with an extremely light all-steel construction, are the lightest motors in use.

DISADVANTAGES.

They consume so much fuel and oil that if we weight them with fuel for a long flight they are heavier than the stationary cylinder type; therefore they can only be used to advantage in short flights. The reason they use so much fuel is that, as they are air cooled they have comparatively low compression; and also that they require between 10 and 12 per cent of the power they develop to rotate the engine, or drive the cylinders through the air.

VEE TYPE.

The vee type engine is a development of the foreign six-cylinder vertical type, resulting from the demand for increased power. By the introduction of the vee principle, the number of cylinders is doubled without increasing the length of the cylinder and with little alteration to the effective width. In practice six-cylinder vertical engines are built in horsepowers up to 200, while 12-cylinder vee engines are built to give some 360 horsepower.

VERTICAL TYPE.

In a vertical engine the cylinders are arranged in a row, standing vertical. Motors with one, two, three, four, or six cylinders are nearly always made in this type. If we attempted to make eight-cylinder motors in this type the cylinders in line would make a very long motor, which would take up too much room in the airplane. The airplane fuselage, and also the crank case, would have to be made quite heavy in order to be stiff enough. Eight and twelve cylinder engines can be built with the cylinders in line or vertical for marine purposes, but are not likely to be built in this way for airplanes. Suppose we built an eight-cylinder motor and arranged the cylinder in two rows of four, side by side. By doing this we cut in half the length and width of the crank shaft and crank case, thus making the motor lighter, more compact, and rigid.

ROTARY AND STATIONARY ENGINES.

In comparing the rotary with the stationary engine it is not possible to lay down hard and fast rules. Broadly speaking, it may be said that the field of the rotary is in the propulsion of very fast small machines of the scout type, while the stationary engine is now employed in practice in every class of machine, but particularly in machines used for making long flights. The rotary is the lightest type of engine for a given horsepower, but it is wasteful in lubricating oil and is relatively inefficient in fuel consumption. It therefore pays to use this class of engine where flights of long duration only are contemplated, so that the advantages of low weight of engine per horsepower will not be counterbalanced by the relatively large amount of fuel and oil to be carried. The rotary engine is also regarded as being less reliable than the stationary, and engines of this type require more frequent overhauling. The average rotary engine must be taken down after 40 hours of running, while most stationary engines can be relied to run some 100 hours without overhauling. From this point of view, however, and in the rotary engine in particular, a very great deal depends upon the design of the

engine and upon the materials and workmanship employed in its manufacture, overhauling, and adjustment. Three out of four of the principal rotary engines have steel rollers without lining, and the pistons are fitted with obturator rings which in the hands of careless or unskilled mechanics would prove a source of perpetual trouble.

TYPES OF CYLINDERS.

There are several types of cylinders used with gas-engine construction, named mostly after the shape of their cylinder head or the location of the valve:

(1) Valve-in-the-head cylinder.
(2) "L"-head cylinder.
(3) "T"-head cylinder.
(4) "I"-head cylinder.
(5) Angular-valve-in-head cylinder.
(6) Four-valve-in-head cylinder.

For airplane use three of these are most common—the angular-valve-in-head type, the valve-in-the-head type, and the four-valve-in-head type.

The angular-valve-in-head cylinder has the valves set at an angle of about 45 degrees, with the heads of the valves seating in the cylinder, and the valves are operated by push rods and rocker arms.

The valve-in-head type of cylinder has the valves placed either vertically or at a slight angle apart, with the heads of the valves seating in the head of the cylinder. This gives a combustion chamber which has no pockets, but the valves must be operated by push rods and rocker arms or else the cam shaft must be placed along the top of the cylinder with small rocker arms operating the valves direct from the cam. In this case the cam shaft is held in an oil-tight housing.

The more square inches of surface exposed to the head in the combustion chamber, the more heat will be absorbed and the greater will be the heat loss. Therefore, the combustion chamber which exposes the least surface to the heat will cause the least heat loss. This also works another way; the cylinder exposing the least surface to the heat in the combustion chamber will require the least cooling. This may mean reducing weight in the cooling system. In the case of high-speed motors it is extremely important to have very direct gas passages. In other words, the gas should be able to go direct into the cylinder and out without having to flow around corners or through pockets in the sides of the cylinder.

The four-valve-in-head type of cylinder gives the most direct gas passage, which means such a cylinder can receive a more complete charge of gas at high speed, and the exhaust gases can be more completely expelled or scavenged.

CHAPTER V.

VALVES AND VALVE OPERATING MACHINERY.

THE POPPET VALVE.

Much depends upon the valves of the gasoline motor; in fact, a great deal of the motor efficiency lies in the condition and operating accuracy of the entire valve mechanism. Since the valves are used to admit the gases to the cylinder and permit their ejection at "timed" intervals, they are the mechanical expression of the actual cycle.

Throughout a long period of mechanical endeavor the accomplished motor attendant has prided himself upon obtaining an accurate set-

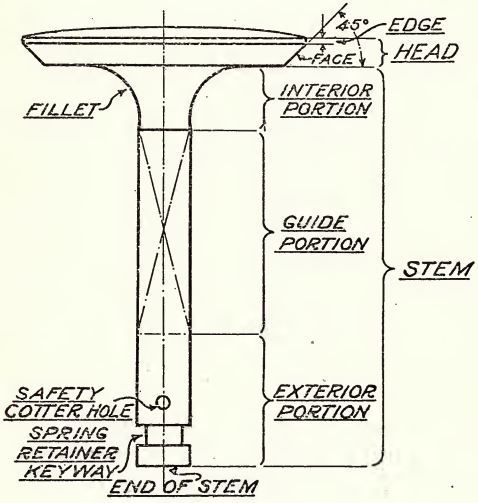

FIG. 2.

ting of the valves upon any motor assigned to him. This fact should emphasize the importance attached to valves as well as to make the beginner realize how careful he must be of the most minor adjustments to this part of the motor mechanism.

There are many kinds and types of valves, but the most common type used in the aviation motor is the "poppet" or "mushroom" valve, so called on account of its action and shape. It preeminently stands first in point of use amongst all other types. The figure above shows the usual design taken by this valve. It has two main

parts, the "head" and the "stem." Of the two, the head is the valve proper, while the stem is the valve lifter, and, as will be noted later, much depends upon the shape and sizes of these parts.

MATERIAL AND THE MAKING OF POPPET VALVES.

The chief considerations in the manufacture of valves is to make them accurate, cheap, and of heat-resisting material. One of the main endurances that the valve must meet in operating service is the high temperatures of the gases passing by or over them. These gases are far above the fusion point of the material of which the valves are made, and if it were not for the fact that much of the heat taken on by the valves was almost immediately given up to water-cooled portions of the cylinders the valves would soon become useless. As it is, the face of the valves, especially the exhaust valves, rapidly become "pitted" or "burned" or "carbonized." It has been found that valves made of certain steels resist the heat action better than others. Naturally, it would be thought that just such a type would be the best, but many engineers object to them on account of other disadvantages that are introduced, one of which is extreme hardness after little service, accompanied by possible brittleness.

Of all the different ways valves are made we will, for simplicity. sum up the process in the following:

(*a*) *The two-piece method.*—The valve head and stem are made separately and by the modern ingenuity of the electric welder or the gas welder the two pieces are jointed. They are then machined and grinder finished. This process makes possible the making of the head of one type of steel and the stem of another; thus the head may be made of costly heat-resisting steel and the stem of less costly wear-resisting steel. Nickel-steel is usually used for the head. The combination is desirable, but the common fault of so many of the valves of this process is that the fillet immediately under the head is frequently too small.

(*b*) *The one-piece drop-forge method.*—A so-called valve blank is formed by the drop-forge method in this process. Nickel-steel is generally used. This type of steel combined with the method permits a very light weight and strong valve to be made. The nickel-steel will withstand considerable heat and will not warp or pit.

However, of all possibilities of heat-resisting material for valves actually doing what the term implies, probably the most earnestly advocated by the aviation engineers is the "tungsten" steel valve. This seems to be the best material found so far for valves. A valve made of it is very hard and will not pit as so many valves do. It can be made very light, as it is free from warping, and the weight of

valves in high-speed motors is a big item. Generally the tungsten steel valve is used with a very narrow seat, possible only by reason of the hardness of its face, giving a free, clear opening, and allowing the passage of gases with least possible resistance. One of the common trade names for a tungsten steel valve is the "Rich" valve. The name is usually imprinted faintly on the top of the valve.

NUMBER AND MOUNTING OF VALVES.

It is the common practice to use one intake valve and one exhaust valve to the cylinder, generally seating against the cylinder metal. Occasional motors are encountered where two exhaust valves and two intake valves are used per cylinder. This latter practice is to obtain more valve opening area for a given sized bore cylinder, as it is always desirous to afford as much valve opening area as possible in a high-speed motor. Duplicating valves in this fashion greatly increases the labor and cost of maintenance. It is best that the student observes carefully the valve setting in the head of a cylinder by taking a detached cylinder in his hands, glancing down the bore and examining the valve ports of the cylinder. He will readily see that there is a decided limit to the size possible for designing the exhaust and intake for a given bore cylinder and yet leave sufficient structural metal in the cylinder head for strength and water jacket space. By examining two or three such cylinders from different make motors he will notice how, in some cases, the designer has skillfully shaped the combustion chamber so as to permit the placing of larger valves than would otherwise be possible.

When a valve is mounted in the cylinder, as shown in the position of Figure 2, it is said to be mounted "vertically head up," the center line of the valve stem being truly vertical and not considered so when parallel to the cylinder center line.

When mounted exactly the other way up from the above it is said to be mounted "vertically inverted." With the same idea, a valve may have "horizonal" mounting or "oblique mounting. Most "valve-in-the-head" cylinders have the inverted vertical or oblique mounting. Most all "L"-head cylinders used the vertical head-up mounting.

MISFIT VALVES AND FAULTS OF SEATING.

Valve efficiency depends upon three things—a gas-tight meeting between face and seat, a correct width of opening, and a correct timing of opening and closing. At present we will discuss largely the first two. It is hopeless to obtain the power out of a motor if the valves leak to a small degree. They must be absolutely gas tight. A small leak is only a small leak for the moment; the hot gases

squeezing through a small leak have the ability to rapidly burn and cut away the steel to such an extent that the action of the cylinder soon becomes useless. With aviation motors this burning away of a leaky valve is much faster than will ever occur in an automobile

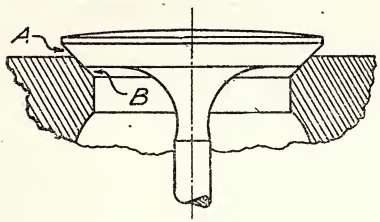

FIG. 3.

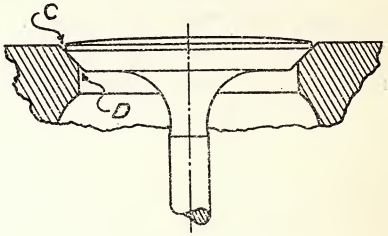

FIG. 4.

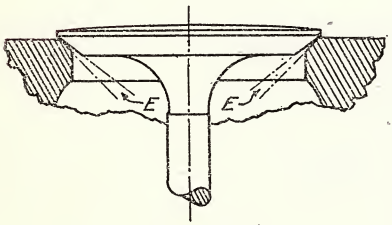

FIG. 5.

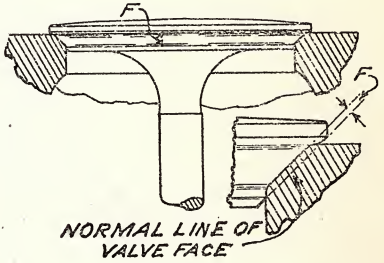

FIG. 6.

motor, on account of the high speed and the full loading of the former.

The valve face should always be wider than the seat; the seat is usually 75 per cent to 80 per cent width. If the seat is too narrow and the face a soft metal, then the face will become rapidly channeled by the seat. The seat impresses itself in the face. This will

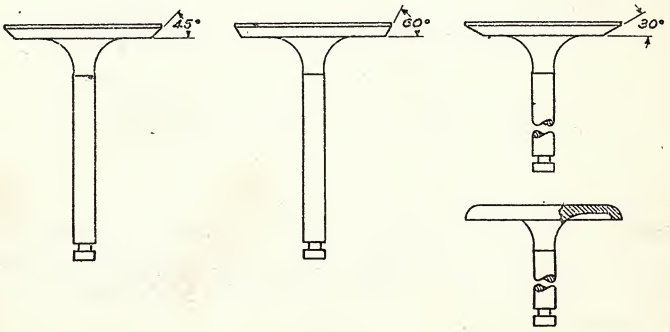

FIG. 7.

happen in course of time, anyhow, and is bound to happen if the valve is overground. It has already been stated that a tungsten steel valve has a very hard face, the tungsten steel becoming very hard when subjected for a short time to the operating heat of the motor.

Such a hard valve face is liable to deform the seat as rapidly as the face channels, therefore, when tungsten steel valves are used, keep as careful a watch on the valve seats as on the valve face.

Much care is to be taken when placing new valves in a motor to see that the valve does not seat too "deep" or too "high." The valve face must cover the seat. If the mechanic is careless in the assembly, he stands a chance of mixing the valves belonging to the various cylinders and thereby placing the wrong valves upon the

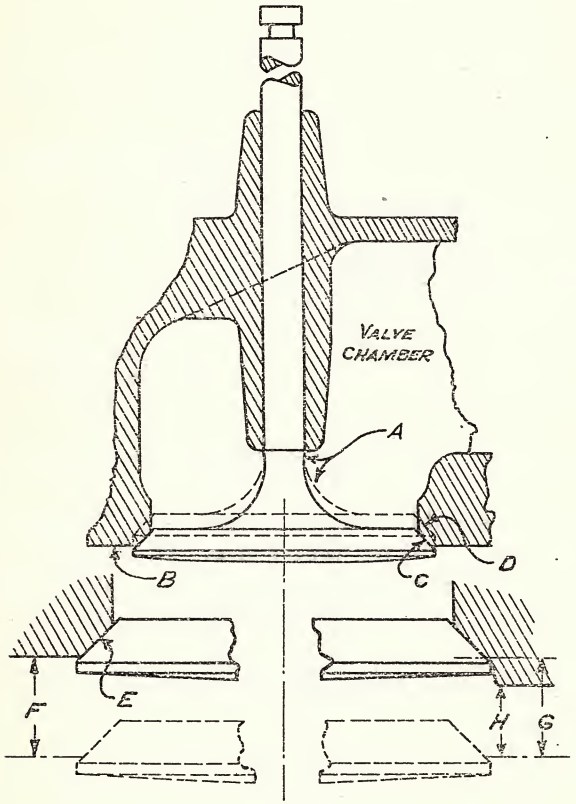

FIG. 8.

wrong seats. The face angles, in such a mishap, may correspond, but the valves may seat too deep or too high, with the result that the seating area is incapable of withstanding the high pressures and the valves burn out.

GRINDING VALVES.

When a valve starts to leak the cause for the leakage is generally the failure of the face to meet the seat accurately at all points. Foreign matter, such as carbon, etc., may have lodged on the seating

area, holding the valve open long enough to become slightly burned. Or the valve may have been held open by improper adjustment of the valve apparatus. However, when the leakage is detected, the valve must be "ground." This grinding procedure is best given in outlined steps:

(*a*) Remove the valve from its seat. This is usually done by removing the cylinder from the motor and releasing the valve spring retainer washer at end of stem, then sliding the valve down into the bore of the cylinder. Motors with removable heads, or of the "L" head type, do not require the removal of the cylinder from the motor.

(*b*) Carefully scrape all carbon from valve head, edge, face, and under head on fillet. This must be done with a piece of brass or material softer than the steel of the valve so as not to scratch it.

(*c*) Carefully scrape all carbon from valve chamber and around seat.

(*d*) Wipe off valve face and seat and inspect both for any irregularities, such as ridges, burned spots, pits, etc.

(*e*) Apply to valve face a little coarse grinding paste. Paste must not be too thick nor so thin that there is danger of it dripping off.

(*f*) Drop valve in on seat and apply holding chuck to end of stem.

(*g*) Methodically grind valve by making, say, a half left turn, raising valve slightly from seat, then a three-quarter right turn, etc., avoiding direct rotation of valve on seat which will cause the grinding compound to make parallel ridges on face and seat. (Note that this process is distinctly different from the *usual* grinding of automobile motor valves, which are heavier with wider faces and seats. This latter type valve is generally milled on head for reception of a screw driver bit and during the grinding process much weight is placed on it at each turn, then it is chattered on the seat violently at each pick-up.) Rough handling of an aviation motor valve, coupled with the frequent grinding it must receive in comparison with the automobile valve, would soon depress it in its seat. (See drawing above for depressed valve seat.)

(*h*) Frequently wash compound off and apply fresh. At first wash off, note valve face critically; see if a dull band is developing around face evenly where contact with seat is made. If dull gray band is not even, either valve face or seat is not true and the fault must be located.

(*i*) When dull gray band is distinct around face (don't attempt to grind out all pits unless a series of them form a path across face), apply some of the finishing compound and grind with a lighter and lighter pressure on valve.

(*j*) Wash off all traces of the compound from seat and valve. Apply a little machine oil and "polish" face and seat with the usual grinding "swing."

(*k*) Again clean and test with gasoline; that is, place valve on seat and pour a little gasoline into valve chamber. Examine from

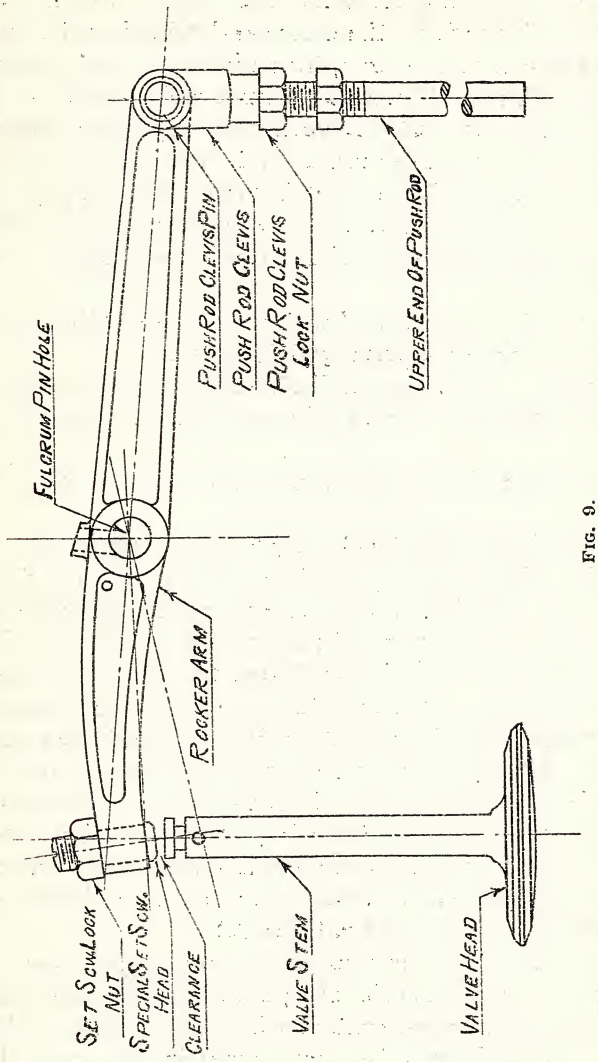

Fig. 9.

cylinder interior for any trace of leakage of gasoline. Wipe off if O. K. and oil slightly.

So many mechanics look upon grinding as a simple easy-go-lucky process and are prone to be very careless and insist that they are expert at the job. This fact makes it very hard to enforce exacting care.

THE VALVE OPERATING MECHANISM.

The character of the valve operating machinery differs widely on the various makes of motors. This difference may be roughly classed under three headings: First, the valve-in-the-head type with the rocker arm push rod system; second, the valve-in-the-head with overhead cam shaft; and third, the "L" head type.

WEAR IN THE VALVE OPERATING MECHANISM.

Naturally, with as many small rapidly reciprocating parts as in the valve operating mechanism upon a motor, wear will take place quickly on some and less quickly on others. This wear affects the motor in two ways, namely:

(*a*) Wear tending to merely "loosen up" the parts.

(*b*) Wear tending to mis-time the valves in their opening and closing, as well as their lift.

The second item is by far the more important and is emphasized in a pamphlet on Valve-Timing. The first may be said to be a matter of mechanical judgment, and when a part, such as a rocker arm pin, becomes noticeably loose, it should be replaced with a larger pin and the parts affected renewed.

AIR LEAKAGE AROUND VALVE STEMS.

It is still further to be pointed out in the discussion on valves that a valve itself may show wear at other than just the face. The stem may wear where it rubs the stem guide, and, of course, if the stem wears, so does the stem guide. Usually the stem guide in large motors is a bushing, a pressed fit to the cylinder head metal. But in the smaller varieties, it is the cylinder metal itself. Short valve stem guides wear quickly and are hard upon the life of the valve stems. The result is that stems and guides do not necessarily last the life of the average cylinder and will become troublesome, in that they allow gases or air to pass to and fro along the valve stem between valve chamber and the atmosphere. In the case of the exhaust valve, the leakage of exhaust gas down the stem tends to overheat the valve by keeping the stem too hot, as a good bit of the cooling of the exhaust valve is dependent upon the conduction of heat from valve head through fillet to stem. From the stem it is given up to the air or cooler guide. In the case of the inlet valve, it allows atmospheric air to pass along the stem and into the valve chamber, thus rarefying the mixture. It is often necessary in the set up of the motor to select a new valve with an oversized stem, as special "spares" are made for motors which have experienced service. In the type of motor with the removable

guide, all that is necessary is to replace the guide. It might be well to caution that the valve stem on the other hand must not fit the guide too tightly. A running fit ample for heat expansion of stem must be assured.

VALVE SPRINGS.

It would be rather short-sighted judgment to express exacting care regarding the fit of a valve and then mount it with a spring that would not at all speeds return it promptly to its seat. Yet mechanic after mechanic has been frequently found guilty of just such misjudgment. This is because the average man is not aware of the rapidity with which a valve spring will weaken under high-speed duty. Then, besides, different motors use different spring tensions for their valves, and it becomes hard to lay down a good rule for detecting a weak set of springs, and therefore too frequently weak springs pass unnoticed.

A high-speed motor requires a strong valve spring to return one of its valves to a seat at high speed. A low-speed motor does not require so strong a spring. The more a valve weighs the harder it will be to promptly return it to its seat. On the other hand, too strong a spring will cause the valve face to channel or ridge quickly and further will cause unnecessary wear upon the valve-operating mechanism. If high efficiency is to be had at high speed, the right spring tension must be secured with light-weight valves.

The spring tension must be such that the exhaust valve can not be sucked slightly off its seat during the intake stroke of the motor, a condition hard to detect upon the operating motor. Most motors have interchangeable valve springs—that is, an exhaust-valve spring that can be used as an intake-valve spring or vice versa. But if there is any difference to be detected in the spring tensions, the weak springs are to be placed upon the intake and the strong ones upon the exhaust. The valve-spring tension increases as the valve lifts, therefore motor data as to spring tensions is always given for the compressed length of the spring when the valve is seated. Two valve springs per valve are not unusual, and afford a construction giving a greater factor of safety; for if one spring should break the other would still seat the valve at low speeds and keep the valve from falling into the cylinder. It may also be said that with the use of two valve springs a heavy, high-speed valve can be returned to its seat with less wear upon the face than if one extra-strong spring were used.

No valve springs should be placed without being first tested. This testing is quickly performed by the use of a common scale. By com-

pressing the spring upon the scale platform to its proper compression length upon the motor, with valve seated, the spring may be "weighed," the number of pounds being the compression pressure of the spring.

Even if the data for the springs of a motor are not available, weak springs are readily detected by weighing them all and picking out the ones below the average. If scales are not obtainable, it is possible to take two springs and place them end to end between the jaws of a vise, noting which one compresses the more. Compare the stronger of the two with the rest, etc., when finally a determination of the weak springs can be made.

On some motors the valve-operating mechanism is so designed that the intake valve is opened by spring pressure and closed by combination spring and cam action. In these cases the heavy springs for valve opening must be weighed in very accurately.

CASE HARDENING VALVE-STEM ENDS.

It is frequently necessary to "square up" valve-stem ends when they have been slightly hollowed out by the action of a contact screw head against them. The squaring-up process, usually grinding a bit off, removes the case hardening. The rehardening is commonly done with cyanide of potassium. One of the best ways to heat the stem so as not to warp it is by the use of a lead bath. The lead is heated past its melting point on up to a red heat, then just the end of the stem held in it until it is red hot. The depth of the dip should be about one-eighth inch. The stem is then dipped into powdered cyanide and immediately quenched in cold water. Do not heat the stem any farther up than necessary. The end is all that needs hardening, and this process gives a very thin, hardened layer to the end. If it is desirable to get the valve stem hardened deeper, it may be held until red hot at the end in a molten bath of cyanide for about 10 minutes, then quenched in cold water, being careful to dip the stem in the water vertically.

CAMS.

The figure below shows the common type of cams that are ground integral with the cam shaft. The exact shape of the cam is very important, and it is impossible to detect wear of even a serious nature by the eye in noting any change from the original shape. Usually wear of the cams is most noticeable just at the valve-opening period or a point practically where the cam engages the cam roller. By a light, quick movement of the fingers over the pick-up point

referred to above, any little hollowing out of the metal can be felt when it can not be seen. The only practical method the mechanic has of detecting cam wear is by the checking up of valve timing. It is therefore highly important that when possible the valve timing

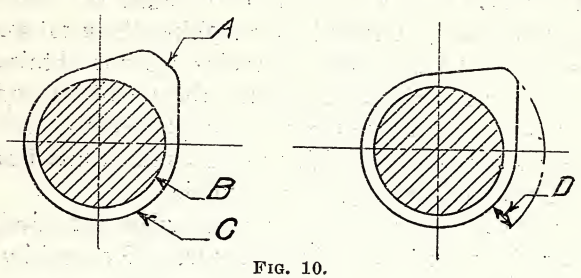

FIG. 10.

should be recorded for a motor prior to dismantling. Then by reference to the shorting of any valve-opening period an idea of cam-shaft condition may be obtained.